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Opportunistic Non-Orthogonal Multiple Access Scheme with Unreliable Wireless Backhauls

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Abstract—The demand for increased connectivity and reliability of devices in the fifth generation (5G) of wireless communications requires new technology for ensuring massive connectivity and high spectral efficiency. In addition, wireless backhauls with guaranteed reliability are being considered to improve the overall system performance. In this paper, we investigate an opportunistic non-orthogonal multiple access (NOMA) system with unreliable wireless backhauls. In particular, we develop two opportunistic selection rules which allow the selection of the best among either near or far-away group transmitters, considering both the unreliability of wireless backhauls and fading effects of fronthauls. In order to analyze the performance, new exact and approximated closed-form expressions for the outage probabilities of the grouped receivers are derived, thus providing an insight into the impact of unreliable random backhauls and opportunistic NOMA. We show that the proposed scheme gives an outage performance gain of more than 3dB gains to a dominant receiver in the selection rules and improvement in receiver fairness when compared to the orthogonal multiple access (OMA) with an unreliable wireless backhaul. In addition, our results clearly reveal that unreliability levels of wireless backhaul links are responsible for the outage floors.

I. INTRODUCTION

Non-orthogonal multiple access (NOMA) is a promising wireless communications technique, which has been recently explored for many applications due to its spectrum efficiency and user fairness for cell-edge users [1].

In NOMA, multiple users can share both time and frequency resources with different power allocation levels. In particular, the users with better channel conditions first remove the messages intended for other users by applying successive interference cancellation (SIC) and then decoding their own messages. It has been extended to a cooperative scenario in [2], where users under good channel conditions can work as relays for other users under poor conditions, thereby enhancing the cell-edge users' performance. A relay selection employing the NOMA scheme has been also proposed to improve the spectral efficiency and user fairness [3], [4].

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Coordinated multipoint (CoMP) transmission techniques have been investigated for multiple base stations (BSs) to jointly support cell-edge users in improving data rates of the cell-edge users. The NOMA scheme for the CoMP network was proposed to support both a near and a cell edge users from the BS simultaneously [5], [6]. Recently, heterogeneous cellular networks along with channel unreliability have been emerging as an interesting research topic in the downlink CoMP networks. Both the impact of unreliable backhaul links on CoMP-based cellular networks [7], [8] and the performance analysis of cooperative system with unreliable backhauls in non-cellular systems [9], have been investigated. The performance of selection combining-assisted cooperative systems with unreliable backhaul connections for non-identical Nakagami- m fading channels has been also investigated [10].

With need for greater connectivity, randomly deployed, ultra dense, wireless small cells will require the use of wireless backhauls to provide the core network. Wireless impairment inherent in these backhauls can then provide a key bottleneck to guarantee reliability and improve the overall system performance. In other words, wireless backhauls will be often unreliable due to the wireless nature of the communication channels [10]. To overcome these challenges, we investigate a new scheme for opportunistic NOMA with unreliable wireless backhaul links. We develop the potential of a joint NOMA scheme and coordinated transmission in an opportunistic manner. The main contribution of this paper can be summarised as follows:

- Two opportunistic selection rules have been developed and applied to the NOMA scheme.
- To analyze the performance, we derive closed-form expressions for the outage probabilities of the relevant NOMA schemes in the presence of unreliable wireless backhauls.
- To the best of our knowledge, this is the first investigation of the impact of unreliable wireless backhauls on the coordinated NOMA system.

II. SYSTEM MODEL

We consider the NOMA system with wireless backhauls in Fig. 1, which consists of one central unit (CU),

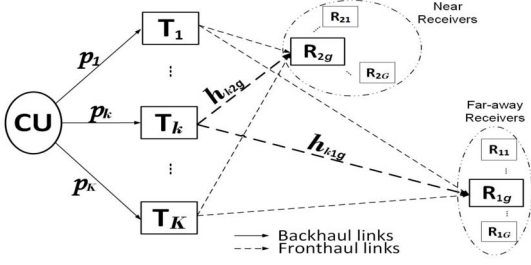


Fig. 1: Opportunistic NOMA fronthauls with unreliable wireless backhauls

K transmitters (T_1 - T_K) and $2G$ receivers (R_{11} - R_{1G} , R_{21} - R_{2G}). It is assumed that the $2G$ receivers are split into G groups of two receivers, each group supported by only one transmitter via an orthogonal channel, and all nodes are equipped with single antenna for simplicity. In particular, each transmitter is connected to the CU via an unreliable wireless backhaul and only one among the K transmitters is opportunistically chosen to convey superimposed messages to each group of two receivers in a non-orthogonal manner. In this way, K transmitters opportunistically support G groups of two receivers. Due to independent operation across the receiving groups, we focus on analyzing one receiving group hereinafter.

Without loss of generality, we assume that the grouped receivers are such that one is selected among far-away receivers and the other is selected among near receivers. We denote the far-away and the near receivers by R_{1g} and R_{2g} , respectively, where $g \in \{1, 2, \dots, G\}$.

For the fronthaul downlinks, we employ the principle of NOMA. In particular, the k -th transmitter for $k = 1, \dots, K$ broadcasts the superposed information $x_k = \sqrt{a_1 P_{T_k}} x_1 + \sqrt{a_2 P_{T_k}} x_2$ to the grouped receivers (R_{1g} and R_{2g}), where x_1 and x_2 are the messages for R_{1g} and R_{2g} , respectively, a_1 and a_2 denote the power allocation coefficients subject to $a_1 > a_2$ and $a_1 + a_2 = 1$, and P_{T_k} is the transmit power at the k -th transmitter. For simplicity, we assume that $P_{T_1} = P_{T_k} = \dots = P_{T_K} = P$. The received signals at R_i is given by

$$y_i = h_{ki} \mathbb{I}_k x_k + w_{ki} \\ = h_{ki} \mathbb{I}_k \left(\sqrt{a_1 P} x_1 + \sqrt{a_2 P} x_2 \right) + w_{ki}, \quad (1)$$

where h_{ki} is the Nakagami- m fading coefficient to express a generalized channel model with a m parameter between the k -th transmitter and the i -th receiver with $i \in \{1g, 2g\}$, w_{ki} represents the zero mean additive white Gaussian noise (AWGN), i.e., $w_{ki} \sim \mathcal{CN}(0, \sigma_n^2)$, and \mathbb{I}_k denotes the backhaul indicator function that represents the status of backhaul reliability. For practical systems, heterogeneous fading distributions are considered for both fronthaul and backhaul links; independent and non-identical Nakagami- m fading links exhibit for the k -th fronthaul whose channel gain satisfies $|h_{ki}|^2 \sim$

$Ga(m_{ki}, n_{ki})$ with m_{ki} is the shape of the gamma distribution and n_{ki} is the scale factor i.e., $n_{ki} = \frac{\mathbb{E}[|h_{ki}|^2]}{m_{ki}}$. To model the independent and non-identical backhaul reliability, we employ a Bernoulli random process and use an indicator function as $\Pr(\mathbb{I}_k = 1) = p_k$ and $\Pr(\mathbb{I}_k = 0) = 1 - p_k$, where p_k is the backhaul reliability probability for k -th transmitter.

For simplicity, we removed the group notation g hereinafter. Therefore, at R_1 , treating x_2 in (1) as an interference, the instantaneous signal-to-interference-plus-noise ratio (SINR) at R_1 from (1) can be expressed as

$$\gamma_{R_1} = \frac{a_1 \rho_{k1} \mathbb{I}_k}{a_2 \rho_{k1} \mathbb{I}_k + 1}, \quad (2)$$

where

$$\rho_{ki} = \frac{P|h_{ki}|^2}{\sigma_n^2} \sim Ga(m_{ki}, \eta_{ki}), \quad \eta_{ki} = \frac{P\mathbb{E}[|h_{ki}|^2]}{\sigma_n^2 m_{ki}}.$$

In order to detect x_2 , R_2 first performs SIC by decoding and removing the message designated for R_1 to decode its own message without interference. Therefore, the instantaneous SINR at R_2 to first detect x_1 can be written as

$$\gamma_{R_{12}} = \frac{a_1 \rho_{k2} \mathbb{I}_k}{a_2 \rho_{k2} \mathbb{I}_k + 1}. \quad (3)$$

The instantaneous signal-to-noise ratio (SNR) at R_2 after the SIC can be expressed as

$$\gamma_{R_2} = a_2 \rho_{k2} \mathbb{I}_k. \quad (4)$$

To opportunistically apply the NOMA transmissions to grouped receivers, we consider two cases of an opportunistic selection scheduling (SS). The first case is that the best among the K transmitters is chosen, taking into account jointly the fronthaul channel from the near receiver, R_2 , and the backhaul reliability, \mathbb{I}_k . The second case is that the best transmitter is chosen, exploiting jointly the fronthaul channel from the far-away receiver, R_1 , and the backhaul reliability, \mathbb{I}_k . Based on each selection rule in the proposed system, the selected transmitter index is given by

$$k^* = \arg \max_{k=1, \dots, K} |h_{ki}|^2 \mathbb{I}_k, \quad i \in \{1, 2\}. \quad (5)$$

III. OUTAGE PROBABILITY ANALYSIS

Now, we will derive the outage probabilities of the grouped receivers. The target SINRs of the two receivers are determined by their quality-of-service (QoS) requirements, that is, its own target SINR, γ_{th_i} , $i = 1, 2$. For simplicity, we assume equal target SINRs for both R_1 and R_2 , i.e., $\gamma_{th_1} = \gamma_{th_2} = \gamma_{th}$.

A. Case I : Opportunistic SS Based on Near Receiver

In this subsection, we derive the outage probability for the first case when the opportunistic SS selects the best transmitter referring to the unreliable backhaul and fronthaul links of R_2 .

1) *Outage Probability at R₁*: Based on the NOMA scheme, an outage event occurs if the transmission does not succeed at R₁. Therefore, using (2), we can express the outage probability at R₁ as

$$OP_{R_1}^1 = \Pr(\gamma_{R_1} < \gamma_{th}) = \Pr\left(\rho_{k^*1}\mathbb{I}_{k^*} < \frac{\gamma_{th}}{a_1 - a_2\gamma_{th}}\right) \\ = \Pr(\rho_{k^*1}\mathbb{I}_{k^*} < \phi_1), \quad (6)$$

where $k^* = \arg \max_{k=1,\dots,K} |h_{k2}|^2 \mathbb{I}_k$ and $\phi_1 = \frac{\gamma_{th}}{a_1 - a_2\gamma_{th}}$. In addition, k^* is the selected transmitter index which depends on h_{k2} . In other words, k^* in (6) is independent of the channel coefficient h_{k1} . Thus, the PDF and CDF of a particular random variable, $\rho_{ki}\mathbb{I}_k$, which is the product of the Bernoulli random process and the Nakagami- m random process [10] are, respectively, expressed by

$$f_{\rho_{ki}\mathbb{I}_k}(x) = p_k f_{\rho_{ki}}(x) + (1 - p_k)\delta(x), \quad (7)$$

$$F_{\rho_{ki}\mathbb{I}_k}(x) = 1 - \frac{p_k \Gamma\left(m_{ki}, \frac{x}{\eta_{ki}}\right)}{\Gamma(m_{ki})}, \quad (8)$$

where $\delta(\cdot)$ denotes the Dirac delta function, $\Gamma(\cdot, \cdot)$ and $\Gamma(\cdot)$ denote the upper incomplete Gamma function [11, Eq. (8.350.2)] and the Gamma function [11, Eq. (8.310.1)], respectively.

Using the law of total probability, (6) can be rewritten:

$$OP_{R_1}^1 = \Pr(T_1 = T_{k^*}, \rho_{11}\mathbb{I}_1 < \phi_1) \\ + \Pr(T_2 = T_{k^*}, \rho_{21}\mathbb{I}_2 < \phi_1) \\ + \dots + \Pr(T_K = T_{k^*}, \rho_{K1}\mathbb{I}_K < \phi_1) \\ = \sum_{k=1}^K \Pr(T_k = T_{k^*}, \rho_{k1}\mathbb{I}_k < \phi_1). \quad (9)$$

After applying (7) in (9), $OP_{R_1}^1$ can be re-expressed as

$$OP_{R_1}^1 = \sum_{k=1}^K \left\{ \underbrace{\Theta_1 \Pr(\rho_{k1} < \phi_1)}_{\mathcal{O}_1} p_k + \underbrace{\frac{1}{K} \prod_{u=1}^K (1 - p_u)}_{\mathcal{O}_2} \right\}, \quad (10)$$

where \mathcal{O}_1 is the probability of the outage event when the best transmitter is selected under the reliable backhaul links, \mathcal{O}_2 is the probability of the outage event when the best transmitter is selected under all the unreliable backhaul links where the outage always happens, and Θ_1 denotes the probability of the best transmitter selection relaying on its unreliable backhaul link and fronthaul link of R₂, which can be formulated as

$$\Theta_1 = \Pr(\rho_{k2}\mathbb{I}_k \geq \rho_{j^*2}\mathbb{I}_{j^*}) \quad (11) \\ = \int_0^\infty \prod_{j=1}^K \left\{ 1 - \frac{p_j \Gamma\left(m_j, \frac{\rho_{k2}}{\eta_j}\right)}{\Gamma(m_j)} \right\} \\ \times \left\{ \frac{1}{\Gamma(m_k)(\eta_k)^{m_k}} \rho_{k2}^{m_k-1} e^{-\frac{\rho_{k2}}{\eta_k}} \right\} d\rho_{k2},$$

where $\rho_{j^*2}\mathbb{I}_{j^*} = \max_{j \neq k, j=1,\dots,K} \rho_{j2}\mathbb{I}_j$. Due to mathematical intractability for Θ_1 in closed-form and high integration complexity, we devise an approximation.

Consider a normalized heterogeneous metric for Θ_1 (effectively, implementing a proportional fair selection) and then Θ_1 can be approximated to be $1/K$. Substituting the series expansion of the upper incomplete gamma function [11, Eq. (8.352.4)], (10) can be approximated:

$$OP_{R_1}^1 \approx \frac{1}{K} \sum_{k=1}^K \left(1 - \frac{\Gamma\left(m_k, \frac{\phi_1}{\eta_k}\right)}{\Gamma(m_k)} \right) p_k + \prod_{u=1}^K (1 - p_u) \\ \approx \frac{1}{K} \sum_{k=1}^K \left\{ \left(1 - e^{-\frac{\phi_1}{\eta_k}} \sum_{l=0}^{m_k-1} \frac{\left(\frac{\phi_1}{\eta_k}\right)^l}{l!} \right) p_k + \prod_{u=1}^K (1 - p_u) \right\}. \quad (12)$$

The accuracy of (12) will be validated through simulation, performing closely to (10). There is a negligible gap between exact and approximated closed-form expressions for the outage probability of R₁ even for small values of p_k . Moreover, notice that the case of small values of p_k when wireless backhauls are highly unreliable, are impractical.

2) *Outage Probability at R₂*: R₂ will be in outage when both the transmission for R₂ and decoding message of R₁ for SIC are in outage. Therefore, using (3) and (4), the outage probability at R₂ can be formulated as

$$OP_{R_2}^1 = 1 - \Pr(\gamma_{R_{12}} > \gamma_{th}, \gamma_{R_2} > \gamma_{th}) \\ = 1 - \Pr\left(\rho_{k^*2}\mathbb{I}_{k^*} > \frac{\gamma_{th}}{a_1 - a_2\gamma_{th}}, \rho_{k^*2}\mathbb{I}_{k^*} > \frac{\gamma_{th}}{a_2}\right) \\ = 1 - \Pr(\rho_{k^*2}\mathbb{I}_{k^*} > \max(\phi_1, \phi_2)) \\ = \Pr(\rho_{k^*2}\mathbb{I}_{k^*} < \Phi), \quad (13)$$

where $\phi_2 = \frac{\gamma_{th}}{a_2}$ and $\Phi = \max(\phi_1, \phi_2)$. k^* in (13) depends on the channel coefficient h_{k2} . According to the theory of order statistics, the random variables of $\rho_{k^*2}\mathbb{I}_{k^*}$ is the largest of K products of Bernoulli and Gamma distributions. Thus, after applying (8) in (13), the $F_{\rho_{k^*2}\mathbb{I}_{k^*}}(\Phi)$ can be derived as

$$OP_{R_2}^1 = \prod_{k=1}^K \left\{ 1 - \frac{p_k \Gamma\left(m_k, \frac{\Phi}{\eta_k}\right)}{\Gamma(m_k)} \right\}. \quad (14)$$

For the non-identical distribution of the $F_{\rho_{k^*2}\mathbb{I}_{k^*}}(\Phi)$, we can apply the identity [10] as follows

$$\prod_{k=1}^K (1 - x_n) = 1 + \sum_{k=1}^K (-1)^k \sum_{t=1}^k \prod_{n=1}^t x_{nt}, \quad (15) \\ \text{where } \sum = \sum_{n_1=1}^{K-k+1} \sum_{n_2=n_1+1}^{K-k+2} \dots \sum_{n_k=n_{k-1}+1}^K.$$

Similarly, after substituting the series expansion of the upper incomplete gamma function and applying the

identity, (14) can be rewritten as

$$\begin{aligned} OP_{R_2}^1 &= 1 + \sum_{k=1}^K (-1)^k \sum_{t=1}^k \prod_{l=0}^{m_{nt}-1} \left\{ \frac{p_{nt} \Gamma\left(m_{nt}, \frac{\Phi}{\eta_{nt}}\right)}{\Gamma(m_{nt})} \right\} \\ &= 1 + \sum_{k=1}^K (-1)^k \sum_{t=1}^k p_{nt} e^{-\frac{\Phi}{\eta_{nt}}} \sum_{l=0}^{m_{nt}-1} \frac{\left(\frac{\Phi}{\eta_{nt}}\right)^l}{l!}. \end{aligned} \quad (16)$$

B. Case II : Opportunistic SS Based on Far-away Receiver

In this subsection, we consider the opportunistic SS to select the best transmitter referring to the backhaul and fronthaul links of R_1 .

1) *Outage Probability at R_1* : The outage probability at R_1 can be formulated as

$$OP_{R_1}^2 = \Pr(\rho_{k^*1} \mathbb{I}_{k^*} < \phi_1), \quad (17)$$

where $k^* = \arg \max_{k=1, \dots, K} |h_{k1}|^2$ and k^* depends on h_{k1} . Thus, (17) can be derived as

$$\begin{aligned} OP_{R_1}^2 &= \prod_{k=1}^K \left\{ 1 - \frac{p_k \Gamma\left(m_k, \frac{\phi_1}{\eta_k}\right)}{\Gamma(m_k)} \right\} \\ &= 1 + \sum_{k=1}^K (-1)^k \sum_{t=1}^k \prod_{l=0}^{m_{nt}-1} p_{nt} e^{-\frac{\phi_1}{\eta_{nt}}} \sum_{l=0}^{m_{nt}-1} \frac{\left(\frac{\phi_1}{\eta_{nt}}\right)^l}{l!}. \end{aligned} \quad (18)$$

2) *Outage Probability at R_2* : In addition, the outage probability at R_2 can be formulated as

$$OP_{R_2}^2 = \Pr(\rho_{k^*2} \mathbb{I}_{k^*} < \Phi), \quad (19)$$

where k^* is independent of h_{k2} . Thus, $OP_{R_2}^2$ can be derived as

$$\sum_{k=1}^K \left\{ \Theta_2 \left(1 - \frac{\Gamma\left(m_k, \frac{\Phi}{\eta_k}\right)}{\Gamma(m_k)} \right) p_k + \frac{1}{K} \prod_{u=1}^K (1 - p_u) \right\},$$

where $\Theta_2 = \Pr(\rho_{k1} \mathbb{I}_k \geq \rho_{j^*1} \mathbb{I}_{j^*})$ with $\rho_{j^*1} \mathbb{I}_{j^*} = \max_{j \neq k, j=1, \dots, K} \rho_{j1} \mathbb{I}_j$. Similar to $OP_{R_1}^1$ in the case I, we implement a proportional fair selection for Θ_2 , and then Θ_2 can be approximated to be $1/K$. Finally, $OP_{R_2}^2$ can be approximated as

$$\frac{1}{K} \sum_{k=1}^K \left\{ \left(1 - e^{-\frac{\Phi}{\eta_k}} \sum_{l=0}^{m_k-1} \frac{\left(\frac{\Phi}{\eta_k}\right)^l}{l!} \right) p_k + \prod_{u=1}^K (1 - p_u) \right\}. \quad (20)$$

Remarks : From (12), (16), (18) and (20), $OP_{R_1}^1$ can be seen to be similar to $OP_{R_2}^2$ and $OP_{R_1}^1$ to $OP_{R_2}^2$ except for parameters Φ and ϕ_1 . For the outage probabilities of the receivers, $OP_{R_2}^1$ and $OP_{R_1}^2$, the best selection rule leads to decrease faster than $OP_{R_1}^1$ and $OP_{R_2}^2$ as K increases. Furthermore, it also can be seen that in both cases for the outage probabilities of R_1 , $OP_{R_1}^1$ and $OP_{R_1}^2$, quickly lead to a lower outage probability as K increases, while $OP_{R_2}^1$ and $OP_{R_2}^2$ slowly lead to lower outage probability

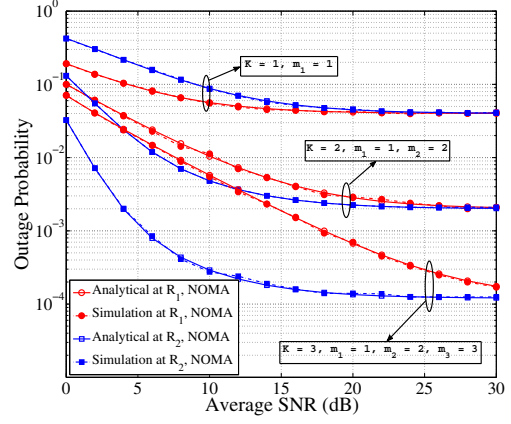


Fig. 2: Outage probability with opportunistic SS based on R_2 for $K = 1, 2, 3$, various values of m_k and p_k .

because Φ is always bigger than ϕ_1 . For the reliable backhaul case ($p_k = 1$), similar observations can be clearly obtained.

IV. NUMERICAL RESULTS AND DISCUSSIONS

In this section, representative numerical and simulation results are given to show the impact of unreliable wireless backhaul links on the performance of the grouped two NOMA receivers. For illustrations, the power allocation parameters are set as $a_1 = 0.8$ and $a_2 = 0.2$, while $\gamma_{th} = 0.1$ dB is used. Non-identical reliability and non-identical Nakagami- m fading channels are considered in the simulation when the k -th transmitter's Nakagami- m parameter (m_k) are $m_1 = 1$, $m_2 = 2$, $m_3 = 3$, and the backhaul reliabilities for the k -th transmitter are $p_1 = 0.96$, $p_2 = 0.95$, $p_3 = 0.94$.

Fig. 2 plots outage probabilities of the grouped receivers with opportunistic SS based on near receiver, R_2 for various numbers of the transmitters, $K = 1, 2, 3$ and their backhaul reliabilities. It shows that when $K = 1$, R_1 achieves better outage performance than R_2 due to their power allocation parameters, but R_2 outperforms R_1 as K increases because the best transmitter is chosen based on R_2 , as shown in (12) and (16). Moreover, Fig. 2 shows that a significant performance gain can be achieved at R_2 by increasing the number of transmitters. In other words, the cooperative system provides a better outage performance than the non-cooperative system ($K = 1$). However, there are outage floors and their dominance is shown in the high SNR region. The rate of convergence to this outage floors depends on m parameter. As the m parameter for R_1 increases, a slower convergence rate can be obtained, whereas when the m parameter for R_2 increases, a faster convergence rate can be obtained. The insights regarding the convergence of the outage floors are similar to the results in [10].

For comparison with the case I, Fig. 3 plots outage probabilities of the grouped receivers with opportunistic

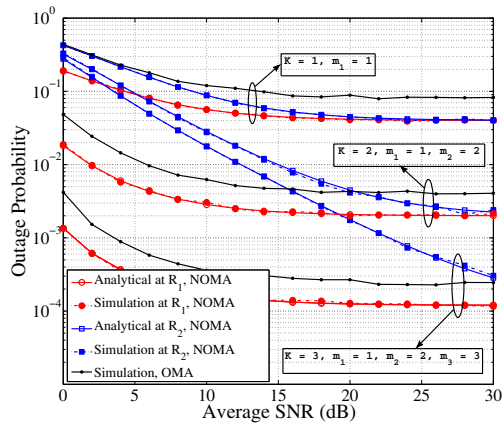


Fig. 3: Outage probability with opportunistic SS based on R_1 for $K = 1, 2, 3$, various values of m_k and p_k .

SS based on the far-away receiver R_1 when $K = 1, 2, 3$. Fig. 3 clearly shows that for the second case, R_1 achieves a outage probability less than that of R_2 . Interestingly, the outage probability for R_1 converges to a constant value in the medium and high SNR regions as m parameter increases, while R_2 slowly converges to a constant for high SNR, as shown in (18) and (20). Moreover, Fig. 3 shows that compared with the traditional OMA with an unreliable wireless backhuals, the opportunistic NOMA with unreliable wireless backhuals can improve the outage performance and receiver fairness, demonstrating the motivation of opportunistic NOMA.

Fig. 4 shows the outage probabilities of the grouped receivers for the case I when $K = 3$, where both reliable and unreliable backhuals are considered. It is clearly shown that reliability of backhaul links are responsible for the outage floors of the outage probabilities. For the impact of m_k , the similar observation with the result in [10] where the rate of convergence on the outage probability is determined by $\min(m_k)$ can be shown. These observation reveals that minimum value of m_k under transmitter cooperation influences the convergence rate to the outage floors in the proposed system.

V. CONCLUSIONS

Opportunistic NOMA with unreliable wireless backhaul links has been investigated. In particular, we have applied two opportunistic selection rules for NOMA. For the performance analysis, the closed-form expressions for the outage probabilities of the grouped receivers have been derived. These provide an insight into the impact of unreliable wireless backhuals and opportunistic NOMA. In addition, we have shown that compared with the traditional OMA with an unreliable wireless backhaul, the

For OMA, we opt to consider orthogonal frequency division multiple access (OFDMA) where each user has the same power, and for comparison and due to complexity issue, the power allocations of both OMA and NOMA are not optimized in this paper. For more details about OMA with unreliable backhuals, please refer to [10].

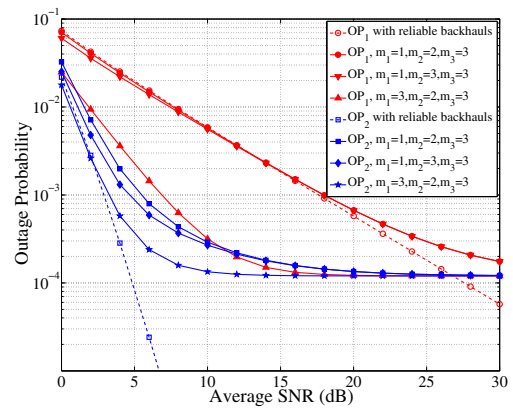


Fig. 4: Outage probability with opportunistic SS based on R_2 for $K = 3$ with reliable backhuals.

opportunistic NOMA with unreliable wireless backhuals can improve the outage performance. The derived analytical expressions are useful to evaluate the performance of various concepts of future NOMA with unreliable wireless backhuals.

REFERENCES

- [1] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. K. Bhargava, "A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 10, pp. 2181–2195, Oct. 2017.
- [2] Z. Ding, M. Peng, and H. V. Poor, "Cooperative non-orthogonal multiple access in 5G systems," *IEEE Commun. Lett.*, vol. 19, no. 8, pp. 1462–1465, Aug. 2015.
- [3] S. Lee, D. B. da Costa, and T. Q. Duong, "Outage probability of non-orthogonal multiple access schemes with partial relay selection," in *Proc. IEEE Personal, Indoor, Mobile Radio Commun. (PIMRC)*, Valencia, Spain, Sep. 2016, pp. 1–6.
- [4] S. Lee, D. B. da Costa, Q. T. Vien, T. Q. Duong, and R. T. de Sousa Jr., "Non-orthogonal multiple access schemes with partial relay selection," *IET Commun.*, vol. 11, no. 6, pp. 846–854, Apr. 2017.
- [5] J. Choi, "Non-orthogonal multiple access in downlink coordinated two-point systems," *IEEE Commun. Lett.*, vol. 18, no. 2, pp. 313–316, Feb. 2014.
- [6] W. Shin, M. Vaezi, B. Lee, D. J. Love, J. Lee, and H. V. Poor, "Non-orthogonal multiple access in multi-cell networks: Theory, performance, and practical challenges," *IEEE Commun. Mag.*, vol. 55, no. 10, pp. 176–183, Oct. 2017.
- [7] Z. Mayer, J. Li, A. Papadogiannis, and T. Svensson, "On the impact of backhaul channel reliability on cooperative wireless networks," in *IEEE Int. Conf. on Commun.*, Budapest, Hungary, Jun. 2013, pp. 5284–5289.
- [8] P. Xia, C. H. Liu, and J. G. Andrews, "Downlink coordinated multi-point with overhead modeling in heterogeneous cellular networks," *IEEE Trans. Wireless Commun.*, vol. 12, no. 8, pp. 4025–4037, Aug. 2013.
- [9] T. A. Khan, P. Orlik, K. J. Kim, and R. W. Heath, "Performance analysis of cooperative wireless networks with unreliable backhaul links," *IEEE Commun. Lett.*, vol. 19, no. 8, pp. 1386–1389, Aug. 2015.
- [10] K. J. Kim, T. A. Khan, and P. V. Orlik, "Performance analysis of cooperative systems with unreliable backhuals and selection combining," *IEEE Trans. Veh. Technol.*, vol. 66, no. 3, pp. 2448–2461, Mar. 2017.
- [11] I. S. Gradshteyn and I. M. Ryzhik, *Table of integrals, series and products*, 6th ed. San Diego, CA: Academic, 2000.